

High-Throughput Methane Pyrolysis for Low-Cost, Emissions-Free Hydrogen

Dr. Brad Rupp, PARC

Cabot, Modular Chemical, Susteon, Stony Brook University, and Burns Energy Systems

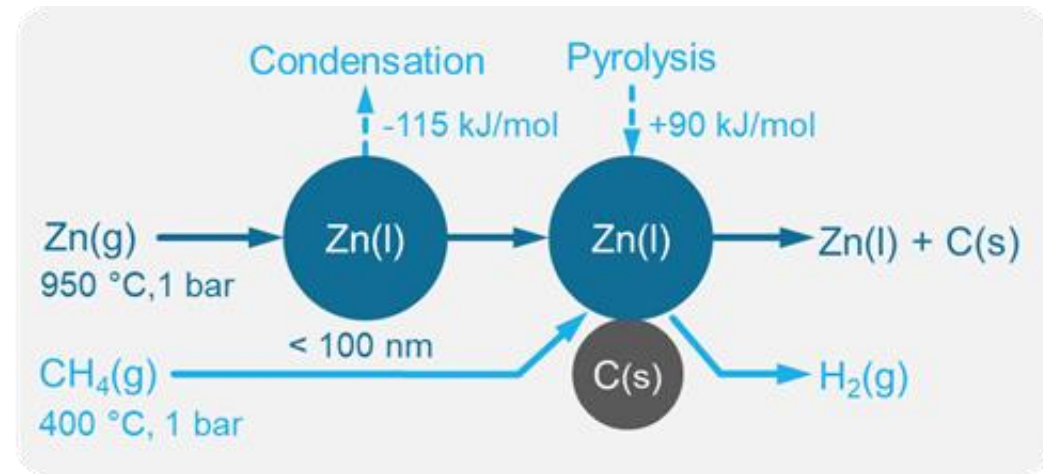
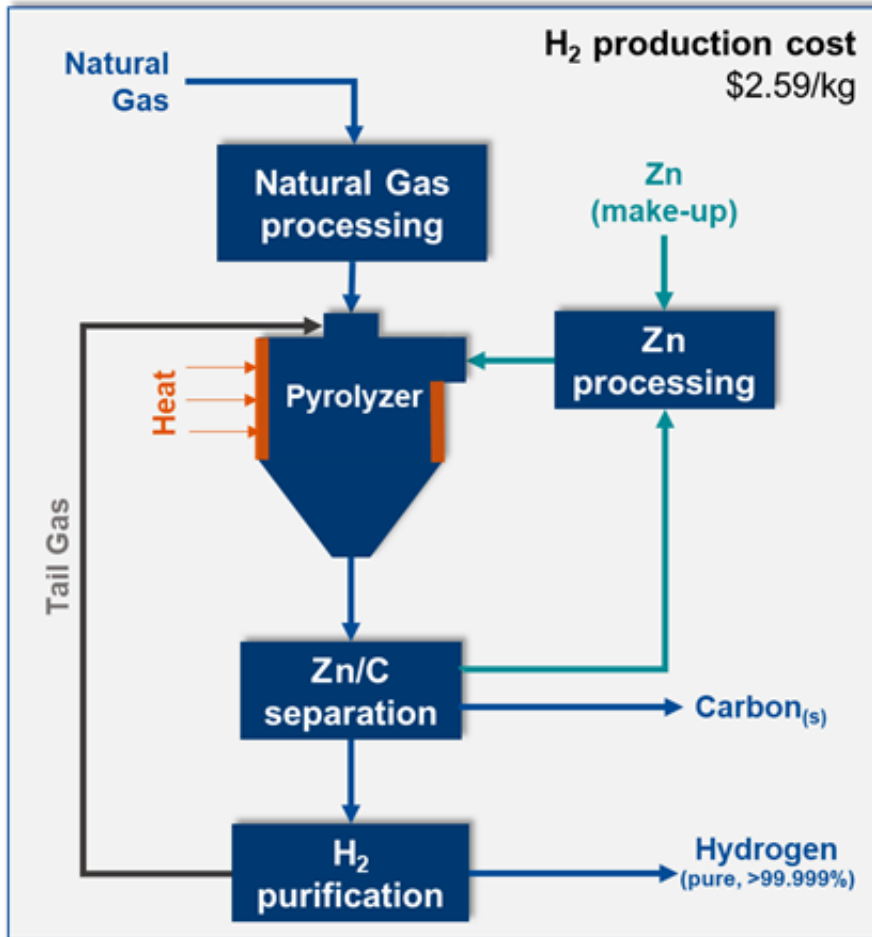
Project Vision

We aim to deliver low cost, emission free hydrogen using a novel condensing liquid metal catalyzed methane pyrolysis reactor that enables modest operating temperatures, high space velocities, and low capital costs

Total project cost:	\$4.2M
Length	42 mo.

The Concept

Zinc condensation catalyzed pyrolysis



Benefits

- ▶ High catalytic activity via high surface area
- ▶ Integration of vaporization and reaction heats
- ▶ Moderate reactor temperatures and pressures
- ▶ Simple and effective carbon-metal separation

Project Objectives

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- ▶ Hydrogen productivity > 20 mol/m³s
- ▶ CO₂ emissions < 3 kg CO₂/ kg H₂
- ▶ Carbon market value > 100 \$/t
- ▶ Plant (1.5 t/d H₂) economics < 3.0 \$/kg H₂
- ▶ Engineering design for 200 kg/d H₂ pilot plant

Final Project Prototype

- ▶ Bench-scale process producing 1 kg/d H₂
- ▶ Reactor space velocity > 1,000 h⁻¹
- ▶ Single-pass methane conversion > 90%
- ▶ Reactor temperature < 1,000 °C
- ▶ Carbon separation efficiency > 99 wt% C

The Team



Brad Rupp
Principal Investigator



Mary Louie
Carbon Separation



Jin Ki Hong
Process Engineering



Jessy Rivest
Project Advisor



Raghubir Gupta
Commercialization
Advisor



Andrew Tong
Bench-Scale Reactor
Development



Vasudev Haribal
Process Modeling



Jim Zhou
Process
Development

The Team



Dane Boysen
Entrepreneur in Residence

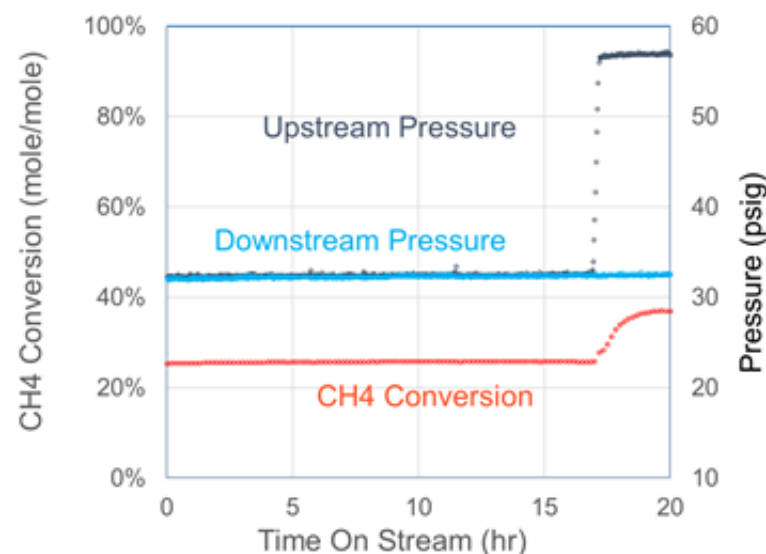
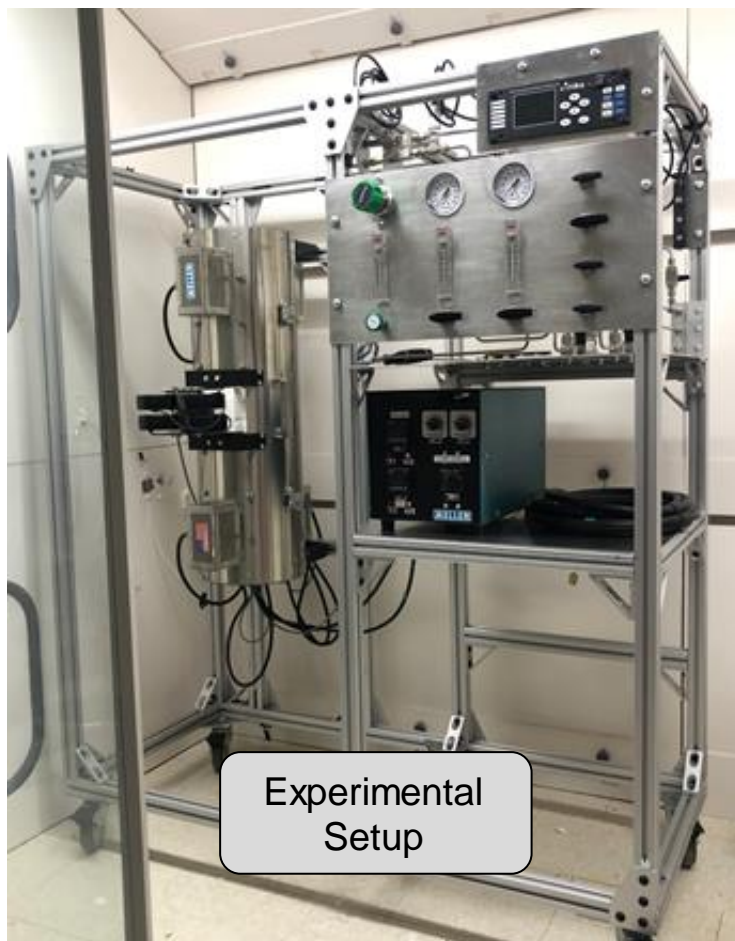


Matt Eisaman
Carbon Characterization



David Matheu
Process Development

Experimental Results

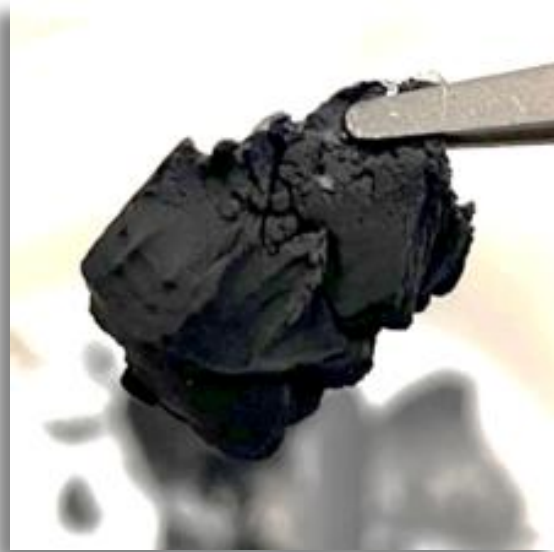


- ▶ Understanding zinc condensation behavior
- ▶ Have shown long term, steady state operation (20 hrs) at moderate conversion (27%)
- ▶ Experiment duration limited by carbon removal
- ▶ Reached conversions up to 60% so far



Carbon Characterization

- ▶ **No thermodynamic limit on zinc-carbon separability**
 - ▶ < 5 ppm Zn in carbon powders separated from proxy Zn-C mixtures
- ▶ **Minimal post-reactor separation expected**
 - ▶ Current lab process produces carbon product with < 1 wt% Zn without post-processing
 - ▶ Other metal impurities at < 100 ppm
- ▶ **Carbon product has potential to be tailored for useful markets**

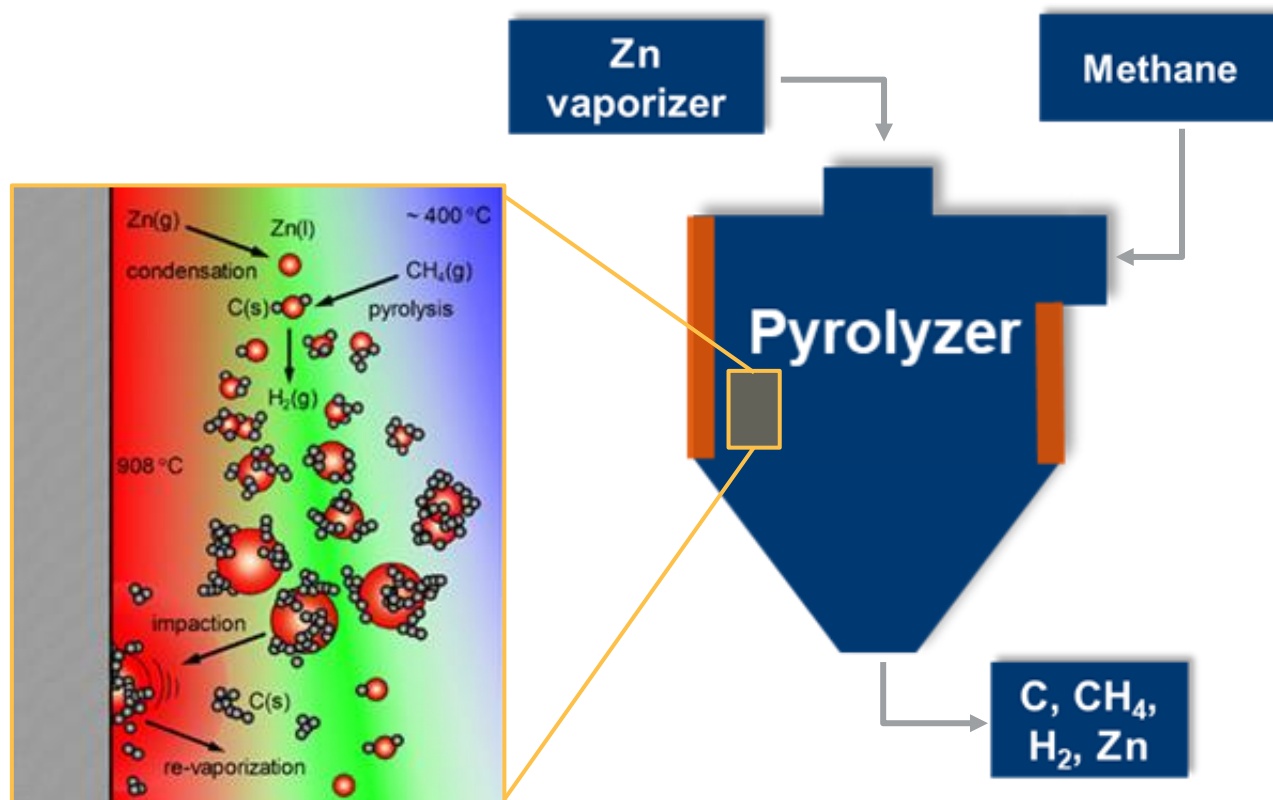


Pyrolysis Carbon Analysis

Concentration (wt%)	
C	98.3
O	1.24
Zn	0.49
Si	0.006
S	0.003
Al	0.002
Fe	0.002 ^a
Cr	0.0006 ^a
Ni	0.0004 ^a
Cu	0.0002 ^a

^a Signal may be largely/solely from the XRF instrument background

Bench-Scale Unit - 1 kg/day H₂



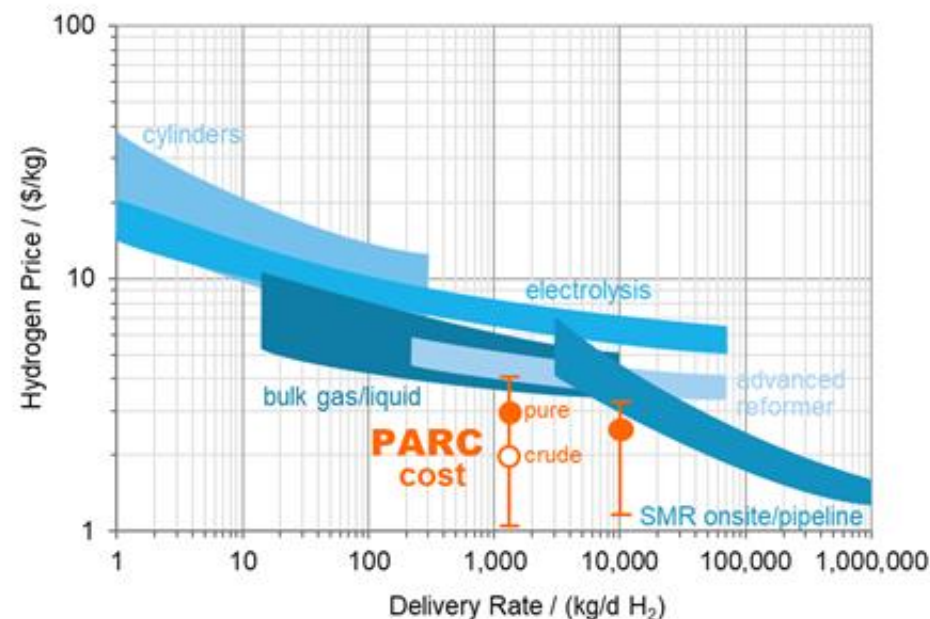
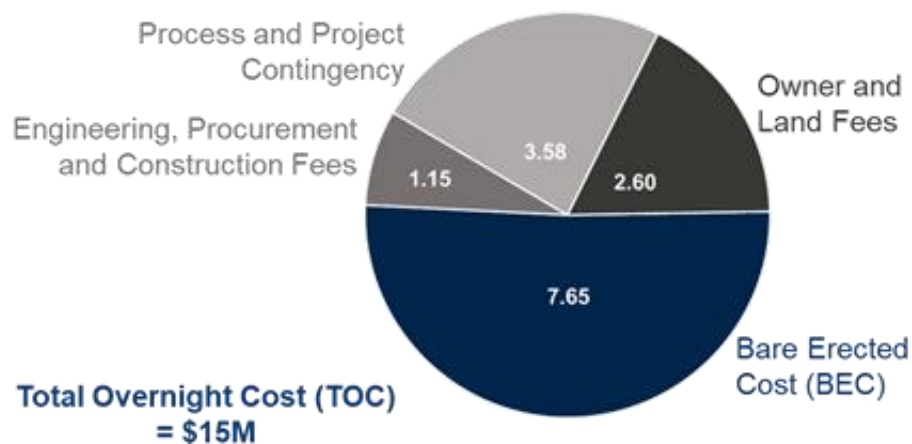
Designed Operating Conditions

Temperature, max	°C	1210
Pressure, max	bar	9.3
Zinc mass flow, max	kg/day	4.5
Methane mass flow	kg/day	4.5
Carbon mass flow	kg/day	3
Hydrogen mass flow	kg/day	1

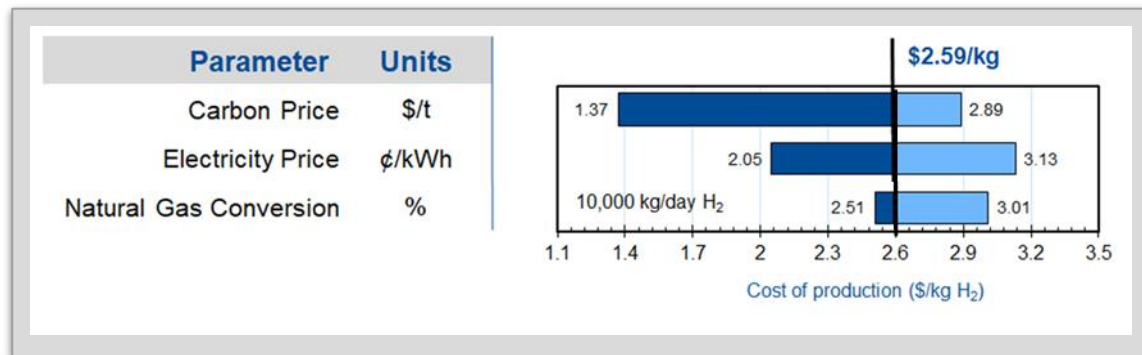
Reactor vessel currently under construction

Techno-Economic Analysis

10,000 kg/day H₂ Plant



TEA shows our process can be cost-competitive compared to incumbent technologies



Challenges and Potential Technical Partnerships

Challenges

- ▶ COVID-19 has slowed progress
- ▶ Commissioning bench-scale reactor slowed due to complexity, finding fabricator, certification process
- ▶ Elevated temperature and pressure process requires care and attention for safe operation

Risk Mitigation

External

- ▶ Slowed project spending early due to COVID-19 uncertainty

Project

- ▶ Continued basic experiments while fabricating reactor
- ▶ Carbon analysis to determine value
- ▶ Exploring reactor design improvements for improved thermal efficiency and carbon product recovery

Partnerships

- ▶ Yes, we're looking for partners!
- ▶ Piloting / scale-up
- ▶ Carbon utilization

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T2M / Potential Impact

Impact

- ▶ Enables low-cost, low-emission hydrogen source
- ▶ Feedstock for cleaner carbon end uses

Current Status

- ▶ TRL 2-3
- ▶ Constructing bench-scale prototype
- ▶ Evaluating carbon for potential markets

Enabling Success

- ▶ Carbon product biggest driver to economic impact
- ▶ Understanding market players and needs crucial to scaling
- ▶ Engaged with Phillips 66 to potentially utilize carbon product

Industrial
Advisors

CABOT 

 **Air Liquide**



Database - Commercial Methane Pyrolysis Efforts

OBJECTIVE

Keep up to date on the latest developments in methane pyrolysis

- We gather information on all commercial methane pyrolysis efforts
- Currently collect 13 pieces of information (shown at right)
- Database has 22 efforts documented--with more to come
- Plan to update database every quarter

Data Collected

1. Start Year
2. Company Name
3. Location
4. Key People
5. Funding / Investment
6. Technical Approach
7. Catalyst / Activator
8. Carbon Product
9. Process Temp, °C
10. Technology Description
11. Commercial Status
12. TRL
13. Website

SAMPLE ENTRIES

Year Started	Organization Name	Location	Key People	Funding	Process Temp, °C	Technical Approach	Catalyst or Activator	Carbon Product	Technology Description	Commercial Status	TRL	Website
2010	Hazer Group	Nedlands (AUS)	Geoff Ward (CEO) Andy Cornejo (CTO, fdr)	\$116,760,000 (mkt cap) Public (ASX:HZR)	900	Catalytic	Iron Oxide	Graphite (80-95% C)	HAZER® Process, iron ore catalyst, produces high purity graphite, fluidized bed reactor, 900 C,	2019 - Pilot plant 100 kg/d H2 situated in Kwinana, Western Australia	7	https://hazergroup.com.au/
2012	Monolith Materials	Lincoln NE (USA)	Pete Johnson (fdr), Robert Hanson (CEO, fdr)	\$64,300,000 MHI, Azimuth Capital	2100	Plasma	Thermal Plasma	Carbon Black	Thermal plasmas allowing over 5000°C temperatures -- licensed technology from Aker Solutions	2018 - Pilot reactor (2MW) "Seaport" (Redwood City, CA) 2021 - Commercial plant (40 tpd C) "Olive Creek, OC-1" (Hallam, NE)	10	https://monolithmaterials.com/
2012	BASF	Ludwigshafen (DEU)	Andreas Bode (lead) Dieter Flick	public-private	1400	Thermal	Solid Carbon	Low Grade Carbon	Moving bed of carbon granules with inductive heating	2014 - Bench scale reactor 2016 - Semi-pilot scale reactor	5	https://www.basf.com/global/en/media/events/2019/basf-research-press-conference.html

THANK YOU!

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